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ABSTRACT

This master's thesis investigates the relationship between the traditional animator and the computer as computer animation systems allow them to apply traditional skills with a high degree of success. The advantages and disadvantages of traditional animation as a medium for expressing motion and character are noted, and it is argued that the complexity of high level interfaces to animation systems will require new ways of thinking about and implementing animated motion. Production of the computer generated film "Tuber's Two Step" by the Computer Graphics Research Group at Ohio State University is related as an example of how conventional planning and timing techniques can be applied to creating animation with a computer. New approaches to animation made possible by the computer are described, and different ways in which animators will approach their work through this new technology are suggested. Supporting materials include 11 figures and 14 references. (MES)

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ROLE OF THE ANIMATOR IN THE GENERATION OF 3-DIMENSIONAL COMPUTER GENERATED ANIMATION

A Thesis

Presented in Partial Fulfillment of the Requirements
for the Degree Master of Arts

by

John Christian Wedge, B.F.A.

The Ohio State University
Fall, 1985

Approved by

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THESIS ABSTRACT

THE OHIO STATE UNIVERSITY

GRADUATE SCHOOL

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NAME OF ADVISOR: Linehan, Thomas E.

TITLE OF THESIS:
Role of the Animator in the Generation of 3-Dimensional Computer Animation

Many computer animation systems emulate methods used in traditional film animation. These systems allow animators to apply traditional skills with a high degree of success. As computer animation systems evolve, many traditional animation tasks will be automated. High level interfaces to animation systems will require new ways of thinking about, and implementing, animated motion. This thesis reveals some of the similarities between traditional animation and computer animation techniques; defines the role of the animator in the development of the new technology; and explores the areas ofanimation that computers are most likely to influence.

Thomas E. Linehan

Advisor's Signature

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INTRODUCTION

In order to understand the process that a computer animator undergoes to produce a piece of high definition character animation, it is necessary to first appreciate the process through which a traditional animator goes. The computer is not simply a replacement for this animator's pencil, or a labor saving device. However, at this point in history the techniques behind the two methods are very similar. Computer animators and graphics programmers are creating a new form of their own. They are, however, taking many signals from the tradition of conventional animation. There is no reason to throw out half a century of animation expertise. There is also no reason to confine computer generated animation to any traditional form.

The terms "traditional," and "conventional" are used here to describe animation that is produced without the intervention of a computer. Only full character animation which strives for the most complete characterization and complexity possible is considered. The work produced at

the Disney studio represents the highest order of this class of animation. Reference is made throughout the discussion to the Disney techniques. This is done at the expense of ignoring several other rich animation styles and approaches. Unfortunately, this shortcoming is unavoidable due to the limitations of space and time. This genre of full character animation is compared to the efforts of a few computer animators who have attempted the same ends through the use of computers. The computer generated film "Tuber's Two Step" is presented as an example of how conventional planning and timing techniques can be applied to creating animation with a computer. This discussion reveals some of the similarities between the two techniques; defines the role of the animator in the development of computer animation technology; and explores the areas of animation that computers are most likely to impact.

Chapter One outlines the advantages and disadvantages of traditional animation as a medium for expressing motion and character complexity as seen through the eyes of the animator. Chapter Two investigates the relationship between the traditional animator and the computer. This discussion has risen primarily from personal interaction

with initially frustrated artists who are confronting computers in an adversarial light. Chapter Three relates the process by which the computer generated short film "Tuber's Two Step" was created at the Computer Graphics Research Group. Chapter Four describes some new approaches to animation that are possible only because of the invention of the computer. This chapter also suggests some of the different ways in which animators will approach animation through this new technology. A conclusion chapter offers comparisons between traditional and computer methods.

CHAPTER 1

What Animators Do

1.1. Motion Analysis

In our lives we continuously experience the physical properties of the world around us. There are clues in the motion of things that tell us what objects are made of, how heavy, how fast, how soft, or how strong they are. We create mental models of the way things should be, and compare them at every moment to the phenomena around us. The slightest aberration from what we expect to see arouses our most rigorous contemplation.

When we view an animated film, we are attuned to the believability with which the motion is portrayed. The characters must appear to be part of a physical world. They must appear to have weight and some measure of strength. The gestural movement of the characters must be appropriate for their personalities.

As a tool to create all of this motion, the animator has nothing but a blank sheet of paper. Absolutely every-

thing in the film is invented. An illusion is created that must be consistent and coherent. All of the elements of this world must stick together, for at the first hint of discontinuity, the illusion ~~exists~~ fades.

Objects that appear in an animated film are weightless, massless entities, unbound by any laws of the mechanical universe. Often when we animate them, however, we are trying to imitate actions that occur in nature. An animator knows how far to move objects from frame to frame to simulate different speeds and properties of objects in the world. This process is called "timing," and is the animator's most fundamental skill.

> Timing is the part of animation that gives meaning to movement. ...A live actor moves muscles and limbs and deals with gravity automatically from habit ...An animator has to worry about making flat, weightless drawings move like solid, heavy objects, as well as making them act in a convincing way [7]. p. 12.

1.2. Advantages and Disadvantages

Animation has always been a time consuming task. The sheer volume of labor required to produce it places limitations on visual complexity, story, and character

development. Animators are forced to consider the most economical way to get a point across. During the evolution of animation, as animators made more demands on the medium, techniques and principles were developed that outlined just what its strengths and weaknesses were. The quotation below reflects the opinion of a Disney studio animator.

> The advantages and disadvantages of our medium are fairly obvious. The advantages are:
> An open field of fantasy and fairy tales never successfully invaded by the regular movies.
> We can make the impossible seem possible and exaggerate to our hearts' content.
> We can rework and simplify scenes until perfection is reached...
> Our disadvantages are stories that are out of reach; there are more of these than there are of the others.
> Our production takes a long time. It is hard to keep the feeling of enthusiasm and consistency for that long a time.
> We can't manage slow movements, and it's hard for us to handle long speeches. Long holds are necessary but tough. ...perspective problems are difficult to combine with drawn acting. Long shots are a problem. It's hard to make our transitions of thought subtle.
> Then there are the little problems, hair, noses, thin faces, graduated shadows, normal human beings, ...muscles - it seems wise to acknowledge these difficulties and avoid them when possible [13]. p. 550.

1.3. Animators are Actors

The allusion to acting in the reference above is especially important. Animators have to understand the characters that they produce before they can possibly draw them. Acting is primarily what an animator does. If the medium happens to be pen and ink, then the animator is performing "drawn acting." When working with a computer the animator may be performing "calculated acting," or "simulated acting," or "interpolated acting," but none the less, it is acting. Character animators are actors that are free to exploit the outer limits of their imaginations. They are not bound by their bodies or by the physics of this world. It would seem, that with enough time and resources, the animator should be able to create absolutely anything.

1.4. Spontaneity

Spontaneity is difficult to achieve in any sort of animation. We want to see an animated character react to a situation as if it were going through it for the first time, as the animator imagined it for the first time. The character's thinking process should be clear and believ-

able to us. Situations should unfold in a coherent, spontaneous fashion. Unfortunately, the process by which we produce animation is anything but spontaneous. It involves analysis of minute changes in motion, and small increments of time. For an animator, it is easy to lose track of the flow of events in the piece. Often the most difficult task for the animator during the production of a piece, is to remain aware of the initial inspiration that set the whole project in motion. The process is slow, and along the way the animator is tempted by new approaches. The animator may feel that the original premise is stale because he or she has become so close to it. That stale premise is finally up on the screen for a very short while, and in order to be clear, must be very cohesive. Therefore, the animator's technique must create as direct a link as possible between the initial inspiration and the realized movement. It is helpful if the animator is able to review the motion that he or she is designing as quickly as possible. Feedback is important. Walt Disney realized this early on in the development of his company, and encouraged animators to "work rough" and "quickly see film of what they had drawn" [13] p. 39.

CHAPTER 2

Animators and Computers

2.1. Hand of the Artist

Many traditional animators complain that computer generated animation looks too mechanical; that it lacks spirit, as though it had been created by a machine. Some of this can be attributed to the near perfect way that a computer has rendered the visual component of the piece. However, the problem for these critical animators is that the motion of objects is too smooth. Nothing in nature, except perhaps the motion of celestial bodies, moves with machine-like precision. Usually computer generated motion is created through the implementation of pristine mathematical algorithms that do not take subtle complexities into account. Every motion that we experience in the outside world is created through the interaction of the intricate, erratic, physical forces of nature. Because conventional animators are not working within the confines of rigid mathematical barriers, they can express subtle, organic changes in movement with relative ease.

Traditionally, animators work with their hands, with materials that have real world physical properties of their own. One might say that a degree of chaos automatically appears in the animation because of this. When single hand drawn pictures are projected on a screen at 24 frames per second, the difference in the drawing quality from picture to picture creates a sense of life and movement by itself. Similarly, in "stop motion" animation, where a solid physical object, such as a model or puppet, is manipulated a tiny bit between exposures, little jittery imperfections appear in the motion that are caused by the lack of precision in the placement of objects from frame to frame. We might consider that these are simply mistakes, and that they detract from the effect of the animation. But these little mistakes instill a life of their own into the motion, by showing a bit of the hand of the animator.

2.2. Control of the Animation

A conventional animator has a high level of control over the objects in a piece of animation. From frame to frame, there is control over every tiny detail of the image. A face can be stretched, a limb can be shrunk, or

an object can transform into another object or character. These changes are made intuitively with the animator's hand. The process is cumbersome, but there is a new degree of control with every grain of pencil lead that grinds into the paper or every thumb-print laid in a lump of clay. The resulting creations are bound only by the animator's particular artistic technique and imagination. Objects in a computer generated film are bound by the technical limitations of the system used to generate it. The animator's style is closely related to the features that the system offers. In most respects, a computer animator has significantly less control than the conventional counterpart has. The computer animator cannot simply touch objects to manipulate them. Somehow, every degree of control has to be piped from the animator's hand, through the computer, onto the object being animated. In order to raise the arm of a character, a puppet animator needs only pull on the wrist of figure a tiny bit between exposures. The cel animator needs only draw it quickly in another position. The computer animator is working with a mathematically defined character database. Joint angles must be specified at every joint that flexes. If the character is to move in three dimen-

sions, each position must be defined in relation to a world origin, by specifying x, y, and z coordinate values. These mathematical abstractions affect the accuracy and spontaneity with which motion can be created. Usually many iterations of the animation must be executed to arrive at the desired movement. As an animation tool, the computer is simply less tangible than physical media.

2.3. Animators and Computers

The animator should understand that the computer is not a labor saving device. It is not simply a replacement for a pencil. Hopefully, it has been chosen for one of its own exclusive properties; perhaps there is no other way to realize a particular idea. Some would say that we are confining it if we use it simply as a tool for producing otherwise conventional films. The machine is certainly capable of stepping out of these bounds.

Computer graphics promises to impact the field of character animation in a revolutionary way. Some animators might consider this a threat to their own job security or to the integrity of "the human element" in animation. It can indeed be perceived as a heartless machine. These

fears are unfounded. The computer as an animation tool has only to be tamed. Those animators who choose to participate in the wave of new technology must understand how the computer works and what it can do. In order to produce expressive animation with it, the animator must have as much control as possible. Whether or not animation systems developed on computers should be modeled after traditional methods is an area for research. Perhaps the computer will open possibilities in character control that have not been considered before. In this case, the manner in which an animator describes animation may take on a form that looks nothing like traditional techniques. Perhaps it is dangerous to limit control of computer generated animation to techniques that were developed over fifty years ago.

The following chapter examines the production of a computer generated film, "Tuber's Two Step." It identifies those instances where traditional animation techniques were incorporated to achieve expressive motion with the computer, and those where the computer could have been of more help. Chapter Four examines the development of new forms of character control, and the pursuit of realism in animated motion.

CHAPTER 3

Production of 'Tuber's Two Step'

3.1. Description of Film

"Tuber's Two Step" is a short film that was produced at the Ohio State University, Computer Graphics Research Group. The images are entirely computer generated. Motion was computer interpolated from key frame positions specified by an animator. The film, as it appeared at the design stage, could have been produced with a conventional, hand drawn technique and perhaps could have been just as successful. However, it was felt that the deep dimensional shading, freedom of camera movement, and "squeaky-clean," rubber surface textures that the computer could offer, would enhance the style of the animation.

"Tuber's" was designed so that it could be produced in a short period of time. Characters and image data were simplified in an effort to reduce calculation time and speed interaction with the computer during the actual animation description phase. The spirit of the film is carried by the movement of the characters. While this

emphasis on movement required a great deal of animation related work, it did not affect the calculation time significantly.

The film presents a short story about a family whose baby takes its first steps. The film runs for just over one minute, and contains sixteen separate scenes. There are three characters: Dad, Mom, and Baby. A fourth character, their dog Fido, was omitted early in the production in order to save time. The word "Tuber's" in the title refers to the clumpy, vegetable-like shape of the characters' bodies. Each character is composed of a number of these organic body parts, which squash and stretch like water balloons. The "squash and stretch" technique emphasizes bounciness, and adds fluidity to the motion. Joints were removed to save time and to simplify the style, so that the separate,"potato-like" parts seem to float in space. Animation of the body parts creates a sensation of visual closure. The discrete body parts form the appearance of a whole character during the animation, as if they were actually attached. The visual closure is less obvious when viewing a still image from the film. The effect is dependent on the motion. It is almost impossible to understand a still image from the film

(Appendix A, figure 1.)

"Tuber's" was designed to break some of the barriers that computers have created for character animation. Efforts were made to avoid the ultra-smooth, mechanical motion that has characterized projects before it. The characters were designed to be non-robots. Many computer generated characters are rigid, only bending at joint linkages. Although this is a characteristic of human motion, humans also have muscle and skin that stretch and contract with the bending of limbs. "Squash and stretch" has become a convention in traditional animation [13]. It is used to exaggerate shape changes on the simplified characters that hand drawn animation requires. The "Tuber" characters were designed to have the boneless, water balloon qualities of squashy, hand drawn characters. Here, however, they would be thrust into the highly defined world of 3-dimensions. The animation conveys a light, happy mood reminiscent of the rich old cartoons that were produced at the Fleisher and Warner Studios in the 1930's. Many of these early cartoons depict insect or animal characters that gyrate through a simple story to the strong beat of a swing band. "Tuber's" used an original jazz score to create an upbeat musical mood for the characters.

The initial design phase unfolded just as it would have for a conventionally animated film. It involved character design, story development, motion design, music composition, and the timing and pacing of individual scenes in the film. When all of this planning was finished, 3-dimensional descriptions of the characters and environments would have to be made and encoded into the computer. In view of the amount of work that this encoding process would entail, all of the design work was done on paper before any interaction with the computer took place.

Thumbnail sketches of character shapes and attitudes were done to explore situations that the characters would portray in the story (Appendix A, figure 2.) These drawings were quick gesture sketches that preserved inspiration by eliminating detail. One is tempted when designing animation to hold onto everything that one has done, to try to fit every idea and sketch into it. It is difficult to generate new ideas in the first place, so it is sometimes difficult to discard them. Gesture sketches usually convey more spirit than a detailed drawing. They are done loosely, and convey simple, straightforward attitudes. They are easy to throw away.

3.2. Design Phase

When the character designs had solidified, storyboards were drawn to depict the actual staging, pacing, and camera placement for the film (Appendix A, figure 3.) Storyboarding is a film industry convention, and is extremely valuable. Usually, a frame is drawn to represent every major action or scene change in the film. This helps the filmmaker get a sense of the visual and temporal continuity of the story. It is a visual extension of the film script. Animation is seldom pursued without a set of storyboards to guide it [7,13,8]

As "Tuber's" matured, small changes were made to the storyboards that reflected new ideas and better stagings. In general, the original boards were followed.

A short outline of the film was created to help keep new ideas on track as the production got underway:

1 10 SECS
main title appears over simple mountains
and plain background.
CAMERA WHIP PANS DOWN to Dad in Medium Shot
running across the plain.

2 3 SECS

door to house flies open. Fido leaps out.
Dad tools into house.
Fido follows excitedly.

3 3 SECS
Mom stirs goop to beat of music.
Dad cruises up behind her.

4 3 SECS
Dad grabs Mom's head, smacks her cheek.
Bounces off to get Baby. Fido jumps and barks.

5 4.5 SECS
Baby crawls across floor.
Dad's hands appear and lift it up.

6 2 SECS
Dad lifts Baby up above his head.

7 4 SECS
Dad tosses Baby into air. Twice.

8 2 SECS
Baby bounces on floor.
Fido appears and sniffs diaper.

9 2 SECS
Mom and Dad look at Baby, beaming.
Mom starts down to pick up Baby.

10 5.5 SECS
Mom picks up Baby like rag doll.
Prods it to start walking. Baby
toddles energetically forward.

11 2 SECS
Mom and Dad respond with excited jumps up and down.

12 2 SECS
Baby is doing a little jig!
Fido is asleep in background.

13 2 SECS
Mom and Dad are doing the little jig.

14 2 SECS

Baby jigs with added fervor.
Fido wakes, looks around in astonishment.

15 2 SECS
Mom and Dad jig back in other direction.

16 4 SECS
Baby jigs out front door of house.
Mom, Dad, and Fido follow.
Whole family exits frame left.
CAMERA WHIP PANS into sky.
END CREDITS pop on to beat of music.

It was intended that the film and the action in the film would move very quickly. The speed of the cutting in a movie often determines the pace of the film. Fast cutting creates a sense of excitement. The length of the shots in "Tuber's" would average those that can be found in an action or chase scene in an adventure movie. Most of the scene changes would occur on continuous motions. This is known in the film world as "cutting on the action." If a character's motion is not continuous from shot to shot, a startling "jerk" will appear, which is known as a "jump cut." "Jump cuts" can also appear because of discontinuities in camera motion or camera placement [10] pp. 213-255. Because the character motion would be so abstract and energetic, and because the cutting pace

of the film would be so frantic, pains were taken to choose the clearest stagings for each shot. Each separate shot is a tiny fragment of the whole film, and carries very little narrative content by itself. Choice of camera angles requires careful planning before animation begins. Each shot has to be animated separately, without the guidance of the shots before or after it. Because of "Tubers'" close production schedule, the entire film could not be viewed until every shot had been completed and edited together. At that point it would be too late to make changes.

> Seeing the picture for the first time is always a startling experience. Somehow it has picked up a life of its own. In some ways it is like one of your children. It may not be what you expected or what you told your friends you'd have, but it's there, and it's yours [13] p. 232.

Design of the animation was done in a number of stages, and relied on the music for timing cues. Beats fell every half second. It was decided that the characters would continually synchronize to this beat by squashing and stretching their bodies. Also, every significant action would land on one of these beats.

Before any computer modeling of the characters was done, hand drawn animation tests were executed to determine if the body proportions and the goofy, bouncy, motion concept would fit together. The Dad character was animated on conventional animation paper and photographed on 16mm film. This conventional process proved to be a much faster way to answer early questions. There was no arduous 3-dimensional data generation step. Changes were made quickly because the drawings were relatively simple. Throughout the production conventional animation was used to design key frame shapes for blending the squash and stretch motions of the characters. This process will be explained further in section 2.4.

3.3. Timing the Animation

The most difficult part of the animation step is the actual timing out of the actions. No matter which medium is being used, paper, clay, or computer, animation cannot begin until the animator has determined which actions will best get the point across; how slow or fast these actions happen, and how they will overlap one another. Once again, animators are actors. They are not simply artists who can draw a figure in many attitudes and from many angles. If

an animated character gives a believable performance on the screen, it is because of the animator behind it. An animator has to "live" the character, think like it, and move like it. The animator must act out each motion. While the experience is fresh the actions that the character would use are analyzed. Each increment of those movements is charted out and drawn. This is very difficult. It is the reason why many animators work behind closed doors. The process involves a great deal of concentration. The only way to explore the character of a fuzzy chipmunk or a dancing vegetable is to act it out.

At this point in the planning phase, many quick sketches were made to represent the strongest attitudes in the sequence (Appendix A, figure 4.) These were made in addition to the sketches made during the initial design of the characters. If this had been a hand drawn film, these sketches might have been used as actual key drawings. Here they were used as guides to refer to during the laborious task of describing the animation to the computer in 3-dimensions. It is often easier to draw a character in a certain pose than to manipulate it, limb by limb, into key positions, in 3-dimensions on a television monitor. The sketches give the animator a guide to follow. There is a

considerable difference between the way we analyze the expressive and entertaining characteristics of a situation, and the way that we implement the tiny details of each motion for animation. The special little problems that the computer and software create along the way require another kind of attention, and distract from the inspiration that an animator must feel when designing a piece of motion. These distracting problems of implementation are inherent in other manual forms of animation, and are dealt with in the same manner.

Before animation begins on a large scale animation production "model" sheets are made that portray each character is a number of angles, and in a number of attitudes. These sheets are used primarily for insuring conformity among the drawing styles of different animators working with the same character. They are used to explore appropriate character attitudes.

Often, however, sketches do not reveal all of the problems with the motion. There are always hidden mechanical impossibilities in the storyboards that do not show up until someone tries to animate them. By sketching as many bits of the scene as possible, some of these impossi-

bilities can be made to appear, and can then be avoided. Some actions are more difficult to communicate than others and require careful planning and sketching if they are to be made understandable. During the production of "Tuber's" some of these arose and were almost impossible to solve at the computer interaction stage. Time spent at the computer usually compounded problems until it was necessary to start the entire scene from scratch. In particular, scene #3 of the film, (Mom stirring a bowl of glop, then Dad scooting up behind her and giving her a kiss,) was difficult to choreograph. To add humor to the scene it was decided that Dad would grab the back of Mom's head with one hand, stretch it as he kissed her, and move in another direction at the same time. Mom's head would then snap back like a rubber band when he let go of it, jostling her so violently that glop would splash out of the bowl. The problem lay in the attempt to change Dad's screen direction in the middle of the action. He had run into the house at such a rapid pace that the sudden change of direction did not seem natural. His body would not have cooperated with such a sudden shift. The resulting animation seemed dead and impossible. It took spirit out of the film. By reworking the staging through rough sketches it

was discovered that Dad's momentum could be absorbed if he smashed straight into Mom. The repercussion of their collision would bounce him naturally off in the other direction. The motion became natural and more humorous. Reanimating this scene consumed over a week of precious production time. After this experience, animation was completely planned and timed on exposure sheets to avoid absolute confusion while describing it to the computer.

Timings for each scene were recorded on conventional animation exposure sheets (Appendix A, figure 5.) These sheets are charts that reserve spaces to describe every frame in the film. Each line contains information about dialogue, music, camera motion, and character movement [7,8] To preserve the silly, synchronized style of the film, each motion had to correspond to some beat in the music. The music was used as an anchor for major poses, (a hand might land on a doorknob on a beat.) In scene #3 Mom stirs the bowl of glop to the beat. This approach made some of the timing easier, and some of it much more difficult. Some actions did not want to fit into a regular beat, so they were not forced. A metronome was used so that actions could be acted out and analyzed. Each "tick" represented some fraction of screen time.

Usually it would be set to tick at a rate much slower than the actual tempo of the music, so that more attention could be paid to the analysis of each movement. It is much easier to break down a slow-motion action than a fast one.

Every beat was charted on the exposure sheet. In this case, a mark was made on every twelfth frame to represent every one-half second. Then a short description of the action that landed at that beat was made. Eventually, the more subtle, overlapping actions were filled in between the major beats. It was not until the exposure sheet was entirely filled in, that any animation data was described to the computer.

Usually, to insure perfect synchronization between motion and music, sound is recorded on magnetic film stock and transposed frame by frame, manually, onto an exposure sheet. Because the musical beat in "Tuber's" was so regular, this stage was unnecessary. Music was recorded after most of the animation had been completed. A digitally produced "click track" was used by the musicians to synchronize to the pre-animated beat. Eight tracks of sound were mixed down in "mono" on one inch audio tape and transferred to one inch videotape along with the completed

animation. Cartoon-like sound effects were added to the video on a separate stereo channel.

3.4. Squash and Stretch of ''Tuber's'' Characters

In order to "squash and stretch" the characters in "Tuber's Two Step," a process called "shape changing" was used. A number of 3-dimensional extreme body shapes were created for a single body part, and the computer interpolated between these extremes for as many frames as were specified. This created the illusion that a single object was changing shape. This is a common solution to the problem of creating fluid objects in computer graphics. It was first introduced in the form of computer assisted 2-dimensional animation systems to automate the time consuming conventional "in-betweening" process [4]. Often, in these 2-dimensional animation systems, a line by line correlation is made between key drawings. The computer can only know about the 2-dimensional lines of the drawing, which actually represent a 3-dimensional model that the animator has imagined [4]. The computer simply interpolates one line shape into the next over the specified period of frames, for every line in the drawing. This requires a fair amount of planning on behalf of the

animator, in light of the chance that as a character revolves, the line segments that represent a back leg, for instance, might disappear. For 3-dimensional shape interpolators, a point by point correlation from object to object must be made, and the polygonal data description maintained, so that the computer can perform a simple linear interpolation between two objects. Thus, a single object seems to change shape (Appendix A, figure 6.)

Each extreme 3-dimensional shape was modeled separately on an interactive data generation system, "dg," [3] by in-putting 2-dimensional profiles of each object on a data tablet and rotating them about a vertical axis, 90 degrees apart from each other (Appendix A, figure 7.) (The same way you would fan a book around into a cylinder by folding the front and back covers together.) This object data type is known as a "solid of revolution" [3] p. 40.

To insure that transitions between key shapes would be smooth, the positions were first drawn and animated on conventional animation paper. Mom's body, for instance, was drawn in the three positions required for a "bounce" cycle. One view was drawn from the front and one was drawn

from the side, as in an architectural building elevation. The animation paper was "flipped" to view the motion. Changes were made to the drawings until the motion was deemed satisfactory. The objects were then described to the computer by tracing the profiles of the drawings on a bit pad. A "solid of revolution" was generated from those outlines (Appendix A, figure 8.)

The characters' heads were modeled with a slightly automated version of a program that existed at Computer Graphics Research Group, named "tog" (Tubular Object Generator) [14] p. 46. Tog can create a tubular object by placing "rings" of specified radii at points on a central line that a user has input, and forming a surface by connecting the rings. The program was modified so that only the curved lines had to be input on a bit pad. The 3-dimensional head would be generated without having to input any outer surface points. The heads were banana shaped, so a line that defined the main curve of a banana shape would be drawn and input by defining ten points on the bit pad. Modifications could be made very quickly. Separate "tog" objects were made for each head, and interpolations were done between them to create squash and stretch motions (Appendix A, figure 9.)

It was intended that the characters would move as if they were made out of water balloons, gyrating in perfect synchronization to each beat in the music. To create a basic "jiggle to the beat" in the main body or torso, three extreme positions were used. The first was a short, squashed out version, and was used to synch with major "down" beats in the music. The second position represented the normal body proportion, and was used to synch with every other "up" beat. The third position was an extreme stretch position, taller and skinnier than normal. It was used for every major "up" beat, which anticipated the first beat of every measure, giving it added punch. Traditional animators recognize that this sequence of extremes produces a "double bounce" effect [2]. It is used to give the characters an extra happy, lively attitude (Appendix A, figure 10.)

Beats in the music fell on every twelfth frame, or one-half second at motion picture sound speed. In order to produce the double bounce pulse of the objects, extreme positions were placed three frames (or 1/8th second) apart in a 1,2,1,3, series. Therefore, body one got the downbeat, bodies one and two were used as the double bounce, (a "little" up and down,) and body three was used to

anticipate the major downbeat, (a "big" up and down.)

For each scene the "double bounce" of the bodies was set in motion automatically, by specifying the keyframe number at which each extreme position was to occur, and by then cycling through them. The actual transformational motion of the characters, in 3-dimensional space, was specified through an entirely separate set of commands.

3.5. Twixt Animation Program

For the most part, the figures in "Tuber's Two Step" were animated in 3-dimensional space with an interactive animation program, "Twixt," [6] which runs on a real time vector graphics work-station. "Twixt" is an "event driven" animation system which allows the user to specify key positions and frame numbers for any geometric object data that is called into the program, including the camera and the center of interest. Three dimensional object transformations are interpolated by the program. Objects can also be attached in a hierarchy, which allows for the construction of human-like characters. Each object has a separate "track" of keyframes, to insure that changes can be made to some objects without affecting the others.

The in between positions that "Twixt" creates are straightforward interpolations that can include "ease-ins" and "ease-outs" to smooth out the motion. The animator defines a frame number with each key position stored, and the number of frames of "ease-in" and "ease-out" desired for the interval between the positions specified. A sinusoidal ease function is implemented that spans the number of frames designated for that period. (Some animators call these "tapers," or "slow-ins" and "slow-outs.") Because the computer is interpolating between key positions, the motion can seem to pause at each key frame. The key positions appear in the final animation exactly as they are described, and if they are not spaced properly, objects can seem to "catch" in certain positions. If an "ease-in" or "ease-out" has been defined to begin or end at a key position, the motion of that object will actually cease momentarily.

The program can also execute a spline interpolation between key positions. Paths of flying objects, for instance, can be created with this type of control. "Keys" in "Twixt" are not limited to positions in space only. Spline interpolations can be done between any scene elements, i.e.: color, lights, or shape changes. "Twixt"

can also accept motion data from external procedures for integration into the animation. This provides the animator with the flexibility to encorporate motion generated by original programs, or motion described by "hand".

"Twixt" represents a family of systems that extend the "keyframing" convention of traditional animation into the 3-dimensional world of computer graphics. A number of these systems give the animator control over objects via knobs or dials that are connected to various transformational attributes of the object, i.e.: scaling, rotating, and translating. In practice, an object, represented in perspective outline on the screen, is manipulated into a key position through the use of a joystick or dial in a "real time" mode. The animator has the sense of turning and placing the object in real time because it instantly responds to the touch of the controls by changing position and perspective. Once a position is established, the frame number for that position is entered, and the next key position is chosen. At the end of the session, the program outputs a list of motion commands, or a "script," that can be used as input to a separate rendering program which will produce a colored, shaded, raster version of each frame for the final sequence. The final moving image

is not seen until some form of calculation is done outside of the animation program (Appendix A, figure 11.)

The rendering program combines the geometric object data, and frame number and position data, with color and shading descriptions for each object to create each still frame. Frames are then recorded one at a time onto motion picture film or videotape. The fully-shaded, animated sequence appears when the images are played back at film or video speed.

The task of an animator using as system like this is not much different than that of a conventional animator. The same approach to timing and pacing that the animator uses with a pencil and sheets of animation paper, can be applied to timing and pacing with the computer. The materials are different, but the approach is not.

The difference between the feel of the motion that appears in a hand animated film and that which is produced by the computer occurs primarily because of the way that key positions are interpolated. Nothing in nature moves with mechanical precision, yet a computer creates movement between two positions in a machine-like manner. The discovery was made early on at the Disney studio that most

motions in nature describe some sort of an arc [13]. In-betweeners were trained to create arcs in motion between the key drawings that animators would give them. It added a natural feel to the motion. If a move was filled in by simply drawing straight between the key drawings, the action was noticeably dead or mechanical. An in-betweener uses knowledge about the way things move in the world to instill the right "feel" in the motion between key frames. The computer knows nothing about the world, only about the two end positions of the move. It obediently creates positions directly between them. As long as the computer is used to do simple interpolation, this "mechanical" motion problem will exist.

Keyframing animation systems are very popular at present, but they by no means represent the extent to which computers can be involved in creating motion for animation. More will be said about this in Chapter Four. It is important to understand that the timing skills that a traditional animator has developed can be implemented with a high degree of success on a system like this, especially if the motion is to have any measure of expression. This system will not make animation easier for an inexperienced animator.

3.6. Conclusion

Animation production at The Computer Graphics Research Group requires a great deal of decision making by the user. The characters in "Tuber's Two Step" could have been endowed with as much life in a more conventional animation environment. The system did not actually create any animation, it produced simple linear interpolations between positions specified by the animator. The system did provide the flexibility necessary to make changes to parts of the animation without throwing other parts out. This flexibility is not found in conventional environments. The system created shaded, highlighted, 3-dimensional imagery that enhanced the bouncy, rubbery feel of the characters.

Conventional animation planning procedures were followed during the production. These were unquestionably valuable during the design and execution of the piece. The system at The Computer Graphics Research Group does not offer the amount of interactivity that would be required to "experiment" with motion during the animation phase of a narrative piece. These planning procedures can be applied to any sort of computer generated motion that is

meant to be presented in narrative film form.

A slightly more sophisticated animation system might have made possible the design of some mechanical relationships in the character models. For instance, the squash and stretch properties could have been produced automatically. Dynamic relationships could been created to regulate the amount of squash and stretch that a character exhibits from moment to moment depending upon the amount of force with which the character hits the floor, the height to which it jumps, or the speed at which it travels. This is an area of research, and is explored in Chapter Four. In the future, lower level motion details will be guided by the animator from a much higher level. This higher level might resemble driving a car. While driving we do not worry about the way that the suspension system and the road beneath it interact, or how the results of that interaction will cause movement in our own bodies [9]. In the future, enhancements such as this will enable animators to create more realistic, less time consuming animation.

"Tuber's Two Step" does not represent a landmark in the development of computer controlled animation systems.

All of the software needed to produce the film, (besides a few simple data management programs that were written to ease the book keeping burden on the animator,) existed at The Computer Graphics Research Group. The production of "Tuber's Two Step" demonstrates how traditional animation skills and techniques can be applied to high-definition, three-dimensional, computer generated character animation, on a system that was designed to emulate conventional animation production procedures.

CHAPTER 4

New Approaches to Animation: Computers and Realism

4.1. Realism and Traditional Animation Techniques

Animators of hand drawn cartoons are allowed a certain measure of freedom to exaggerate movement. This is partially because there is relatively little realism expressed in the rendering of their characters. Classic cartoon characters have become simple, pliable little beings that are expected to be able to defy laws of gravity. The more that a character begins to express realism in its form, the more an audience expects to see the character's motions conform to realism. A three-dimensional, computer-generated character has been given very convincing shading and highlighting qualities. It seems to have real form and real substance. It appears to occupy real three dimensional space. This invites the viewer to look for clues about the mechanical properties of that space. This is where the computer animator's technique must diverge from the traditional simple keyframing techniques. As our computer generated geometric models

and rendering capabilities become more representative of reality, our motion models must become more sophisticated. Future computer animation systems will have to include computational models of the mechanical world that we are accustomed to. These can take a number of forms, and range from characters that know about simple dynamic relationships between parts of their bodies, on up to characters that contain some sort of "personality."

The term "reality" here does not refer necessarily to the generation of realistic human characters, or to the the rendering of "natural" scenes. As an image encorporates higher visual resolution, it provides a clearer, more direct representation of the scene it contains. The image begins to conceal the process that rendered it. This quality can make a fantastic image seem real by exhibiting qualities that we associate with reality, not by simply depicting reality.

If an animated character is to be entirely believable it must seem to exist in a world of continuous, stable physical properties. It is the animator's responsibility to understand and convincingly portray the effects of external forces on the character, and the forces that the

character exerts on its environment. Innumerable tiny manifestations of these properties of cause and effect occur all around us. The portrayal of these complex systems by hand becomes a formidable task, and the skill of an animator is often measured by the ability to do this convincingly. It is not difficult to imagine why the traditional animator is concerned with simplification and clarity in composition and motion.

The computer is well suited for detailing these complex, important motions. Animation systems that integrate dynamic simulation with character descriptions and environments promise to make a significant contribution to the generation of realistic character motion.

4.2. Computer Simulation

Richard Lundin [9] describes a system that creates some realistic motion details as a post process to key-frame interpolated animation. The program applies simple dynamics formulae to the motion of robot characters to insure that wheels touch the ground while rolling over uneven terrain, or that springs and suspension systems recoil convincingly.

With the Bbop [12] animation system, an animator creates keyframe positions for 3D articulated objects which are interpolated with cubic spline techniques. The animation might consist of the path of a robot through a certain area. This would normally be the final animation step. The simulation program takes this animation data, performs the intended dynamics operations on it, (eg., fills in the little bumps and bounces that the robot feels as it scoots across the terrain,) and outputs new transformations for the objects. The animator has control over parameters of the dynamics model which might make the robot bounce higher, or make its suspension system more rigid. The output animation can be fed back through the simulation program until the revisions are deemed satisfactory. New dynamics models are implemented depending on the type of object or motion desired in the scene. These straightforward mechanical details add astounding realism to the animation. They create a level of motion complexity that is not attainable with keyframing techniques.

4.3. Forward vs... Inverse Kinematics

Often, when keyframing a computer generated figure, it is impossible to coerse extreme appendages of a

character's anatomy to remain in a single position, (such as a foot on the ground, or a hand on a door knob.) This is because the appendage is nested under a hierarchy of limbs that attach it to the character's body. (The root of the structure is often at the character's chest or torso, not in its hands or feet.) This is known as the "forward kinematic" approach to positioning the character. The position of an extreme appendage occurs as a result of the concatenation of joint rotations of the limbs above it in the transformation hierarchy. This problem can be solved by temporarily placing the root of the hierarchy at the hand or foot, and redefining the hierarchy every time that another appendage requires anchoring. This means that as a character walks, the root of the transformation hierarchy must change from foot to foot at the appropriate moments. This is a cumbersome solution, and limited to cases where only one object requires anchoring at a time. Inverse kinematic control allows the animator to place the extreme appendages, or "end effectors," of a character's anatomy, and let the program work out the required transformations of the connecting limbs back toward the body. This technique can be likened to the manner in which a puppeteer manipulates the limbs of a marionette.

Keyframing with forward kinematics, on the other hand, requires that adjustments be made discreetly to each joint, which can become tedious, especially for complex motion where accuracy is critical.

4.4. PODA

Currently, at The Ohio State University Computer Graphics Research Group, a project is underway that applies robotics research in inverse kinematics and walking machines to multi-legged character motion. Micheal Girard [5] has created PODA, a program that creates animation of complex, articulated figures through the implementation of pseudo-inverse kinematics. At its lowest level, PODA solves for joint angles in complex limbs connecting extreme appendages, or "end effectors," to the main body of the figure. The animator must specify a preferred angle for each joint, which that joint tries to maintain. A "gain" factor is also applied to each joint that defines the extent to which each joint will resist rotation. This allows the animator to define the flexibility of each joint, and in effect, the manner in which the character will bend. An elbow or knee may be defined to give way more easily, while other joints will remain more rigid,

such as the joints in the spine. Also, with a number of parameters, the animator is able to describe temporal relationships between limbs that allow the construction of any number of bi-pedal or multi-legged animal gaits.

Once the dynamic properties of the figure have been constructed, the animator can describe the motion of the figure from a higher level. The animator may describe a path through which the figure is sent at a specified speed, and all specific foot-hold and gait calculations are taken care of by the program. The figure automatically runs through the path. PODA imposes Newtonian mechanics on the figure, forcing it to lean into turns and to conform to the laws of gravity. Enhancements to the system will include the ability to define the strength and weight of separate members of a character's anatomy, which will contribute to its ability to jump, run or spin. The approach that PODA has taken allows expansion to "task level," or "goal directed" motion. At this level, after defining the complex series of tasks required for a figure to open a door, for instance, an animator can command the figure to "open the door," and expect the figure execute the motion by itself. High level commands of this nature can be linked together to create complete sequences [5].

PODA forces the animator to include a notion of dynamics in the character as a fundamental design consideration. The animator is creating a physical universe in which the characters will move and perform. Because a system such as this contains such complete physical constraints, an animator is not able to simply create the geometric form of a character and worry about how it will move later. It is harder to "cheat" motion in an environment where mechanical laws prevail. The animator must not only understand why the character moves, but how. Realistic simulation may relieve the animator of detailing every single motion, on a frame by frame basis, but it does not relieve the animator of the responsibility of understanding the characters, and creating motivations for their actions.

4.5. Behavior Simulation

Systems are being developed that will relieve the animator of the tedium of coordinating large groups of figures. Animating a flock of birds, for instance, can become an overwhelming task if each bird must be keyframed separately. The ability to set a large group of figures running along in a herd by using a few control parameters

represents a tremendous advantage over the traditional practice of having to attend to each figure separately [1]. These systems involve the implementation of collision avoidance and "force-field," algorithms, and fall under the category of "behavior simulation" animation systems [11]. Imagine a herd of creatures created by a simulation program, constrained by real-world mechanics, avoiding collisions among themselves just as they might in nature. An animator, after having designed the mechanical characteristics of the separate figures, might simply input a series of points that define a general path, and run the herd of the figures through it.

Susan Amkraut has created a program at The Computer Graphics Research Group that uses mathematically defined "force-fields" to direct the motion of objects in a scene. The "force-fields" can be made to take on any number of shapes by manipulating various parameters that define them. Simple attraction or repulsion forces, or more complex orbital or spiral forces can be defined. The program also provides the ability to attach these forces to individual objects. Objects can be made to avoid colliding with each other in this way. When directing the motion of a flock of birds, for instance, a three dimensional space

curve can be created which defines the path of a single bird. This bird can have a great attractive "pull" on the other birds in the flock. It can also have a small repulsion effect on other birds, so as they get near it, they are repelled gently away before the collide with it. Each of the other birds in the scene can carry gentle repellent forces which make them avoid collisions with each other. By controlling these attraction/repulsion parameters, the animator can create characters that seem to be making decisions about how to avoid each other while following the same general path.

These systems point to a future where computers will allow the implementation of "smart" characters. There is no reason why, along with the physical and dynamic description of a character, an animator cannot include information about the characters personality. It is conceivable that characters could be designed with so much sophistication, that when placed in a situation with other characters, and given some form of motivation, could actually act a scene out to some logical conclusion. This system would contain complex descriptions of character personalities that would call on massive task level motion libraries to execute high level directions from an

animator. The animator would interact with these characters as though they were actors on a set, by providing them with a script, and motivations and emotions. This may appear to be a naive projection, at best distant goal, but some research has already been conducted in this vein for simple characters in very simple environments [11].

The advancement of simulation systems will impact the way in which animators think about and implement animation. As these systems evolve, the role of the animator is subject to speculation. Perhaps these systems will offer the environment of spontaneity that has been missed up until now. Perhaps they will allow animators to perform more like actors, or in the distant future, directors of actors. It is possible that they will create a more personal animation environment, one in which a single person has control over every aspect of the production. As computer hardware becomes more affordable, a new class of independent animation production might be introduced. Tasks that have, until now, been handled by assistants will be handled by the computer. Films generated by computer my begin to bear very personal stamps of single filmmakers.

On the other hand, with the development of complete constraints on character movement, the animator may become lazy. Attention will no longer have to be paid to giving characters weight or strength. With the introduction of artificial intelligence personality databases, the animator may not think so completely about the consequences of character interaction. Perhaps the complexity of these simulated environments will become so severe that animation will be left up to physicists and programmers. In this case, perhaps animation skills as we know them will become unnecessary.

CHAPTER 5

Conclusions

The emergence of simulation systems may reduce the tedium associated with creating character animation, but it will not relieve the animator of the responsibility of performing most of the fundamental skills that are associated with creating animation. Computers offer new approaches to solving the same problems that animators have been addressing for a long time. These include realistic character motion, complex environments, detail in general, and most importantly, personal creative expression. Working with the computer, the animator is still faced with determining how a situation can be presented in the clearest manner; how to take full advantage of the tools available; and how to avoid solutions outside the capabilities of the system. The animator may be asked to control parameters like "stride length," or "elasticity" to describe a character's walk, or to assemble a sequence of actions out of smaller actions that he or she has already been defined. The creative decision making process behind these techniques have been applied to anima-

tion in the past, now they are simply being applied to the computer animation technology.

To best apply animation skills to the new technology, it is essential that the animator understand the new animation system as completely as possible. The conventional animator uses tools of a relatively simple nature. The uses of paint and ink, pen, and paper are intuitive to most of us. The technique that the animator has developed involves the use of these tools on a level far removed from the simple understanding of what they are and how they work. The tools have become a transparent vehicle for the realization of ideas. Suddenly, when introduced to the world of computers, the animator struggles to understand the new tool on just this simple level. It is unreasonable to expect that this animator will be able to create high level animation programs immediately, although he or she may know exactly what features would be needed to create the "ultimate" system. The animator may not realize the potential of the computer animation machine, and become satisfied with a technique that does not express the extent to which either the animator or the machine can produce animation. It is important, therefore, in the development of skills that relate to computer

animation, that the animator understand the computer as much as possible. An understanding of programming languages and graphics algorithms will certainly contribute to the process of making the computer more "transparent." However, in light of the fact that computer technology is constantly advancing, this not a one step process. The compulsion in the computer world to stay abreast of the cutting edge of new technology does not exclude the humble computer animator. It may seem to this "naive user" that he or she is playing a constant game of "catch-up" with more literate computer experts.

Graphics programming is a highly specialized field which requires knowledge in areas that an animator has perhaps ignored while developing skills as an artist. Likewise, a graphics programmer may not have developed aesthetic sensibilities that contribute to successful animation. For these reasons, there are advantages to having teams of animators and programmers work together to produce animation environments. In this way it is more likely that systems will develop which include sophisticated graphics capabilities and flexible, intuitive user interfaces. The creation of successful computer animation requires the cooperation of these disciplines. Whether or

not all of these these skills are embodied in a single individual is unimportant. As in any other endeavor cooperation is essential, and will become even more so as evolution in the field creates more specialization.

Computer animation systems will make possible a renaissance for character animation. This will not arise through simple emulation of the extraordinary traditional animation of the past, but by building a new vehicle for creative expression on top of it. Through the combination of animation expertise and the power of computer technology the limitations that conventional animation has presented will be overcome. In this respect, computer character animation will open a truly limitless realm of creative expression.

APPENDIX A

Figure 1.
High resolution images from ''Tuber's Two Step''.

Figure 2.
Thumbnail sketches used for character design.

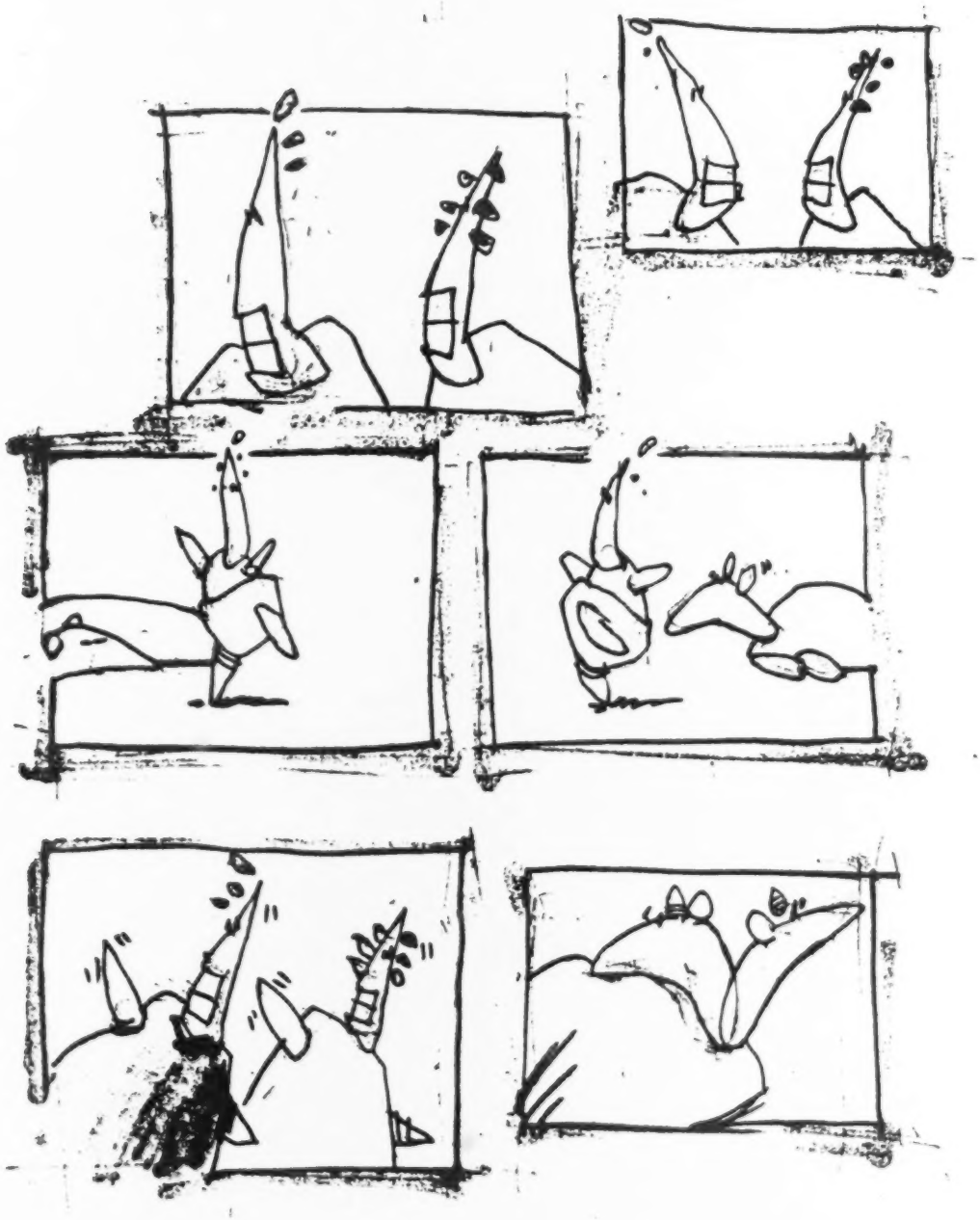

Figure 3.
Storyboard illustrations.

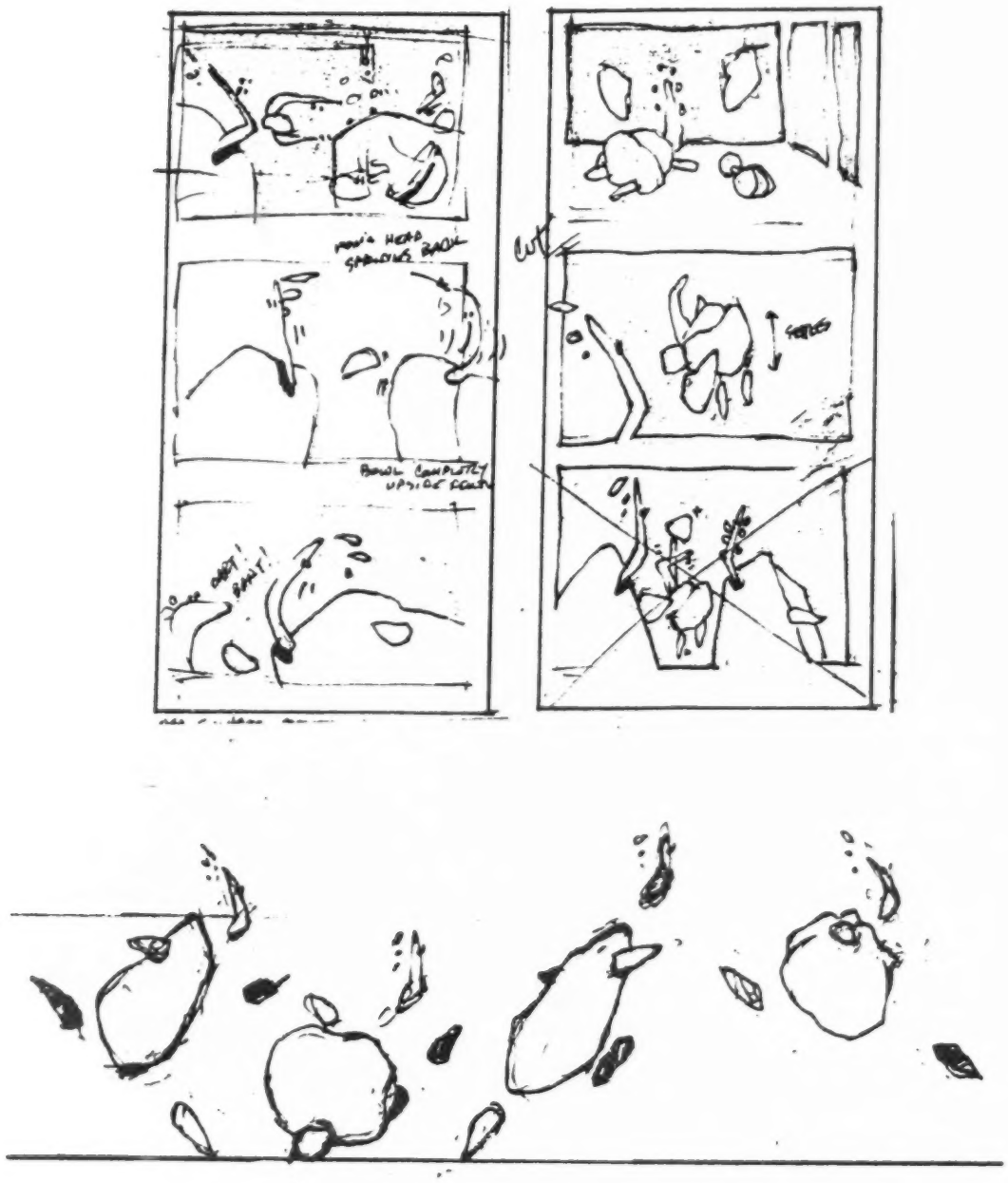

Figure 4.
Thumbnail sketches for motion design.

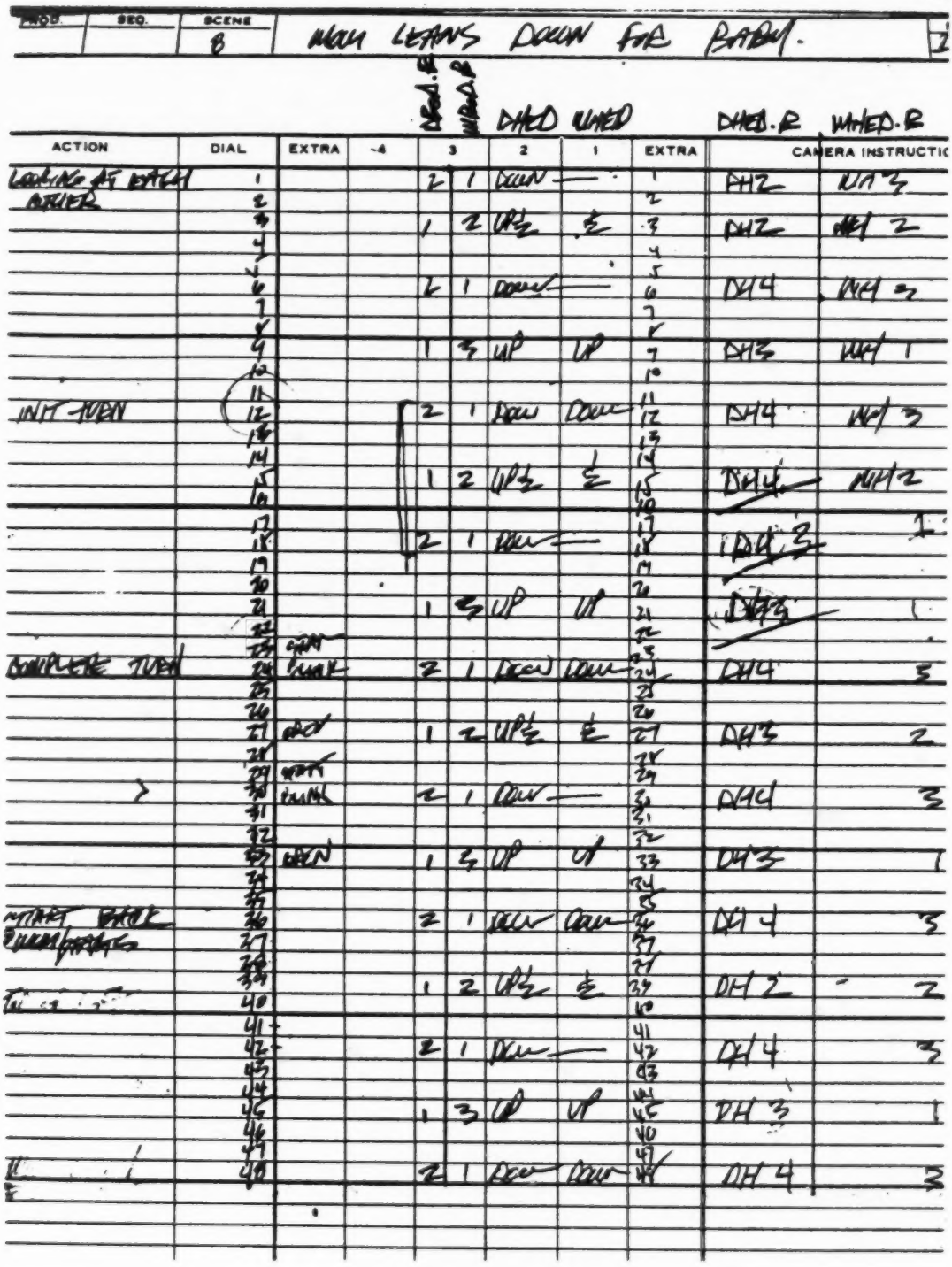

Figure 5.
Exposure sheet with timing marks.

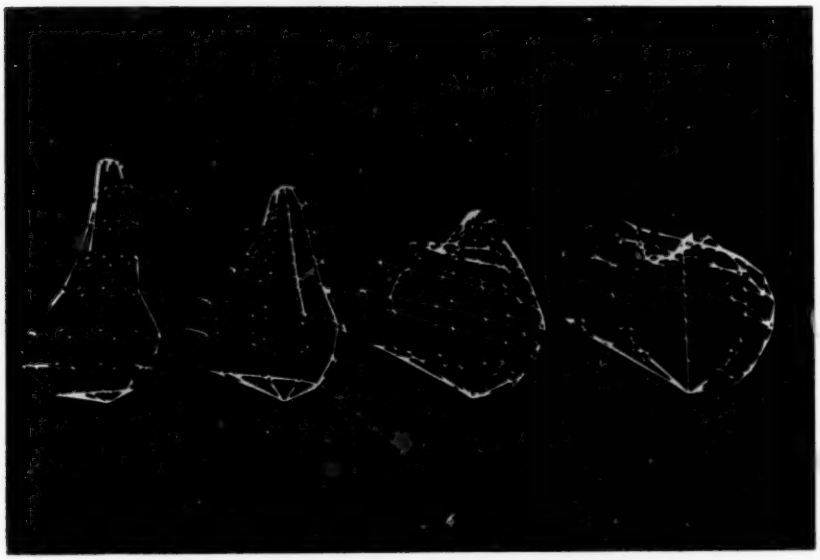

Figure 6.
Linear interpolation between 3-dimensional objects.

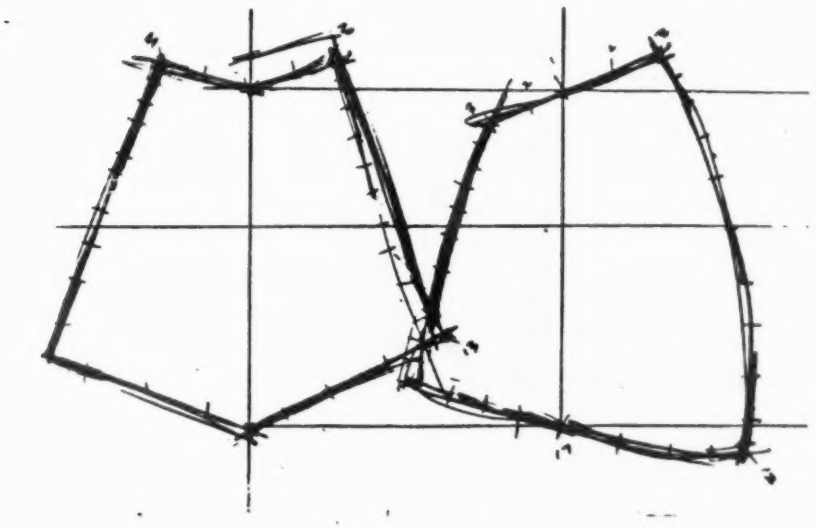

Figure 7.
Hand drawn profiles for 3-dimensional data.

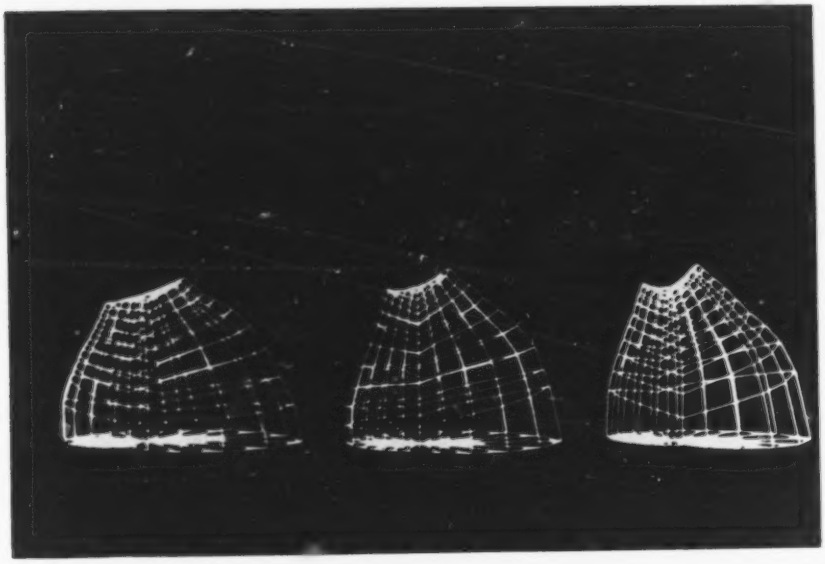

Figure 8.
"Dg" data.

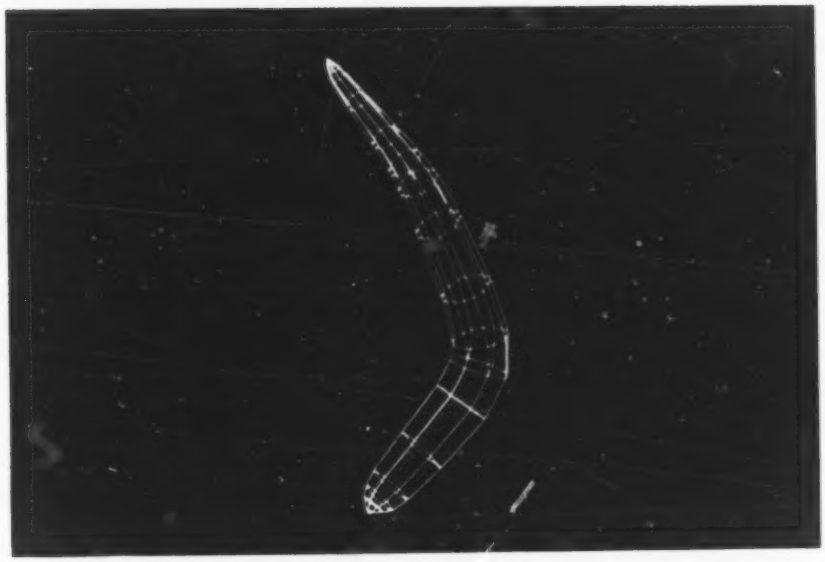

Figure 9.
"Tubular" object.

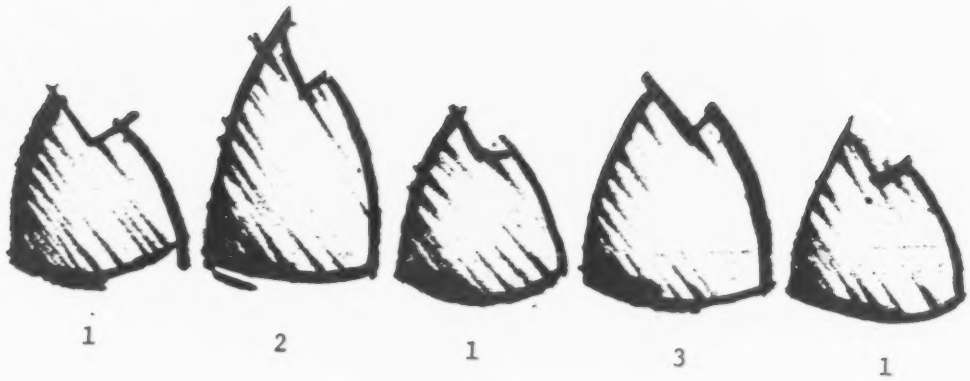

Figure 10.
Cycle of change shape bodies.

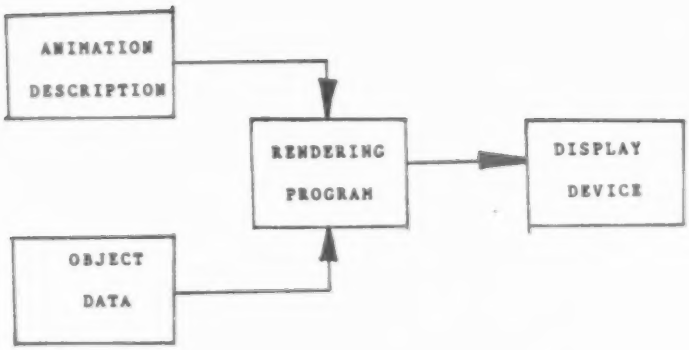

Figure 11.
Computer Graphics Research Group animation flow chart.

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